New ways of cooling

– information for building designers

- Technologies to lower energy consumption and CO_2 emissions
- Key parameters that affect the performance of each technology
- Possible combinations of technologies
- Support to the CD-ROM 'SELECT' (System for Evaluating Low Energy Cooling Technologies)

BEST PRACTICE PROGRAMME
ENERGY EFFICIENCY

BEST PRACTICE PROGRAMME

Front cover illustration:

BRE's Environmental Building makes use of night-time cooling with natural ventilation (page 8) and ground water cooling (page 13), both of which are renewable sources of cooling, which were novel at the time of its construction.

This Report is a companion to the CD-ROM 'SELECT' (System for Evaluating Low Energy Cooling Technologies), which provides further information on the practical combinations of system components, and the conditions that would lead the designer to the selection of a particular low-energy cooling technology. The CD-ROM and this Report are produced by BRECSU for the Government's Energy Efficiency Best Practice programme (EEBPp). The CD-ROM is available from the BRECSU Enquiries Bureau (see the back cover for contact details).

This Report draws its information from the IEA Annex 28 report 'Selection Guidance for Low Energy Cooling Technologies' and an internal report 'A Review of Low Energy Cooling Technologies Appropriate for Use in UK Buildings' prepared by The Welsh School of Architecture. The draft text, illustrations and CD-ROM were prepared by Oscar Faber.

CONTENTS

1 INTRODUCTION

Buildings in the UK are currently significant users of conventional cooling systems, which are usually electrically driven. This Report aims to make building designers in the UK more aware of some less familiar cooling technologies that have the potential to reduce energy consumption and carbon dioxide (CO_2) emissions.

The technologies considered by this Report are listed across table 1, in the following categories.

1 Night storage systems
2 Ground coupling systems
3 Alternative HVAC systems
4 Delivery systems

The Report also considers how some of these technologies can be used in combination.

USING THIS REPORT

Table 1 enables you to shortlist appropriate cooling technologies for further examination. Consider which design factors apply to your project, from the list on the left of the table. Cooling technologies that can exploit these conditions are indicated by a tick (✓) and a page number next to each title, where a further explanation may be found. Some circumstances can only be served by conventional heating, ventilation and air-conditioning (HVAC) systems, and these are indicated by the right hand column.

Section 2 of this Report summarises each technology on the pages indicated in table 1, and includes:

- a brief technical description
- an illustrative technical diagram
- favourable design factors and limitations
- design aims and requirements to be considered.

The bullet points within section 2 refer to building parameters that affect the effectiveness of the technology such as internal heat gains, building location, and environmental control requirements, etc. A major factor affecting the use of most low-energy technologies is the limited capacity of some single systems to meet large building cooling loads. Therefore it is sometimes necessary to consider the use of two or more technologies in combination.

The matrix in section 3 identifies combinations that are possible between the technologies that are being considered. At the intersection of two technologies there will either be an 'S', 'P', or nothing. An 'S' indicates that the technologies can be used in series, a 'P' indicates that the technologies can be used in parallel, while a blank cell indicates that the technologies should not be used in combination.

A series combination implies that the technologies can work in series as part of one cooling system, for example the use of aquifers to provide cool water for use with chilled ceilings. A parallel combination implies that the technologies could work alongside one another, with each meeting part of the cooling load, for example displacement ventilation and chilled ceilings.

Further assistance with selection and combination of cooling technologies can be found on the companion 'SELECT' CD-ROM.

INTRODUCTION

Shortlisting of suitable technologies	Night storage systems				Ground coupling systems				Alternative HVAC systems				Delivery systems			
Design factors that favour each technology	Night-time cooling with natural ventilation (8)	Night-time cooling with mechanical ventilation (9)	Hollow core slab cooling using air (10)	Enhanced surface heat transfer system (11)	Ground coupling using air (12)	Ground water cooling (aquifers) (13)	Ground coupled heat pumps (14)	Surface water cooling (sea/river/lake) (15)	Evaporative cooling (direct/indirect) (16)	Desiccant dehumidification and evaporative cooling (17)	Absorption cooling (18)	Ice storage (19)	Slab cooling using water (20)	Chilled beams/ceilings (21)	Displacement ventilation (22)	Conventional HVAC systems (23)
Ambient air temperature/humidity																
■ Large diurnal temperature range, night <20°C	✔	✔	✔	✔												
■ Low ambient air humidity									✔							
■ Ground temperature <12°C					✔											
Internal conditions																
■ Cyclical heat gains	✔	✔	✔	✔												
■ Requirement for low humidity										✔						
■ Close temperature/humidity control required																✔
■ High internal and/or solar heat gains																✔
■ Surface temperature of heat sources >35°C															✔	
Local geology																
■ Located on sand/gravel or below water table					✔											
■ Aquifer accessible						✔										
■ Movement of ground water					✔	✔	✔									
■ High soil conductivity							✔									
■ Inter-seasonal heat storage if no ground water movement							✔									
■ Proximity to sea/river/lake								✔								
Power/heat costs/availability																
■ Waste heat or cheap thermal source available										✔	✔					
■ Spare boiler capacity											✔					
■ High electricity costs										✔	✔					
■ Large differential between peak and off-peak electricity costs												✔				
Other benefits																
■ Could use for heat storage in winter			✔													
■ Suitable for retrofit				✔												
■ Compatible with low-energy/quality sources of cooling													✔	✔		

Table 1 Categories and types of cooling technologies

2 TECHNOLOGIES FOR NEW WAYS OF COOLING

NIGHT-TIME COOLING WITH NATURAL VENTILATION

This method makes use of the free cooling available from the ambient air at night. The building is naturally ventilated at night with ambient air from open windows and/or vents. This has the effect of cooling the building fabric, and removes any stored heat gains accumulated during the day.

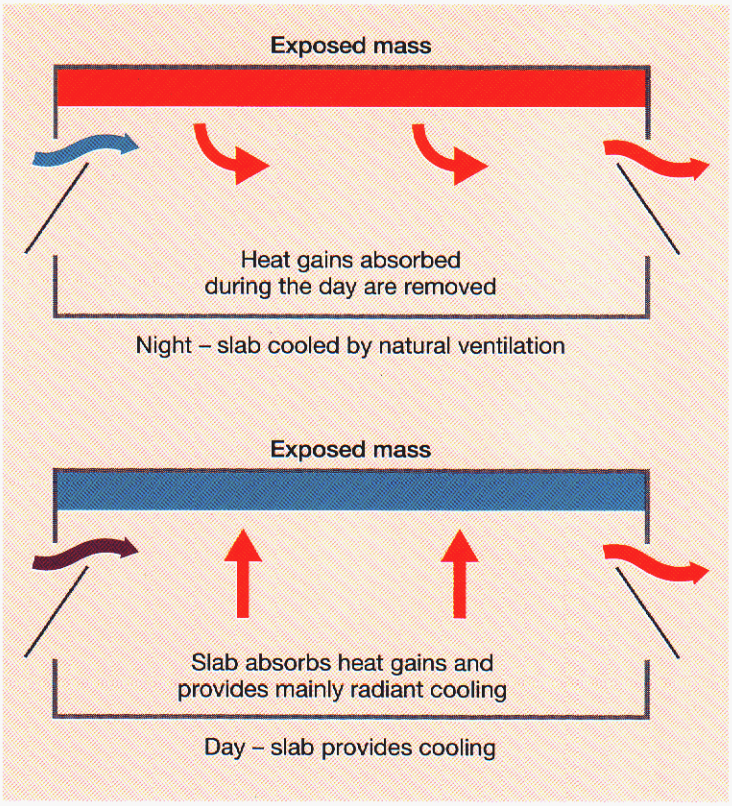
In buildings where there is a significant amount of exposed thermal mass, the free cooling at night can be stored in the fabric and used to offset heat gains the following day.

Generally, night-time cooling with natural ventilation requires an exposed ceiling slab to provide sufficient storage of cooling energy and allow effective heat exchange to take place. The slab may be coffered or profiled in some manner to maximise the effective surface area. Perforated ceilings can also be used, although the convective and radiant heat transfer between the slab and the room will be reduced. Automatic controls on windows and vents could be considered to prevent overcooling.

During the day, the mechanisms of cooling are essentially the absorption of heat gains by the cooled slab, and radiant cooling from the slab. Daytime natural ventilation also provides additional free cooling, although during days of high ambient temperatures it may be preferable to limit the ventilation rate.

Night cooling of exposed heavyweight constructions can offset around 20-30 W/m^2 of heat gains during the day, reducing peak internal temperatures by around 2-3°C.

Because the slab is relatively cool, it provides radiant cooling to the occupants. This may allow the air temperature to be slightly higher while still giving satisfactory comfort conditions.



Favourable design factors

- Large diurnal ambient temperature range with night-time temperatures below 20°C.
- Cyclical heat gains.

Application limitations

- Best if heat gains <30 W/m^2.
- May be difficult if there is noise and/or air pollution.
- Unable to give close temperature and/or humidity control.
- Can be awkward in deep-plan/cellular space.

Design aims

- Achieve cross-ventilation air flow.
- Avoid overcooling.
- Minimise internal and solar gains.
- Balance cooling benefit against possible winter heating impact.

Design requirements/concerns

- Effective air/fabric thermal linking.
- Security and privacy.
- Openable windows and vents.

TECHNOLOGIES FOR NEW WAYS OF COOLING

NIGHT-TIME COOLING WITH MECHANICAL VENTILATION

This method makes use of the free cooling available from the ambient air at night. The cool ambient air is used to ventilate the building using fans or a central air supply system. This has the effect of cooling the building fabric, and removes any stored heat gains accumulated during the day. In buildings where there is a significant amount of exposed thermal mass, the free cooling at night can be stored in the fabric and used to offset heat gains the following day.

Mechanical ventilation provides the means for controlling the air flow, avoids the need to leave windows open overnight and bypasses problems with noise and pollution.

The main factors that affect the performance of such a system are the pressure drops through the ventilation system and the control strategy used. The higher the pressure drops the greater the fan energy consumption and heat gain in the air stream.

Night cooling of exposed heavyweight constructions can offset around 20-30 W/m^2 of heat gains during the day, reducing peak internal temperatures by around 2-3ºC.

Because the slab is relatively cool, it provides radiant cooling to the occupants. This may allow the air temperature to be slightly higher while still giving satisfactory comfort conditions.

Favourable design factors

- Large diurnal ambient temperature range with night-time temperatures below 20ºC.
- Cyclical heat gains.

Application limitations

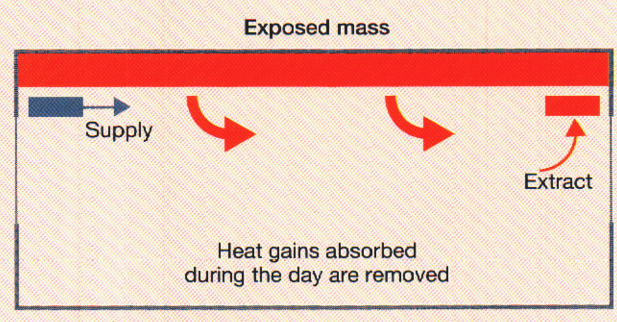
- Better if heat gains <30 W/m^2.
- Unable to give close temperature and/or humidity control.

Design aims

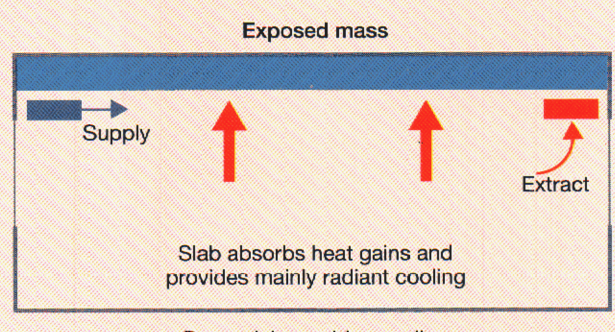
- Minimise fan pressure drops.
- Avoid overcooling.
- Minimise internal and solar gains.
- Balance cooling benefit against possible winter heating impact.

Design requirements/concerns

- Effective air/fabric thermal linking.
- Space for ventilation system.



Night – slab cooled by mechanical ventilation



Day – slab provides cooling

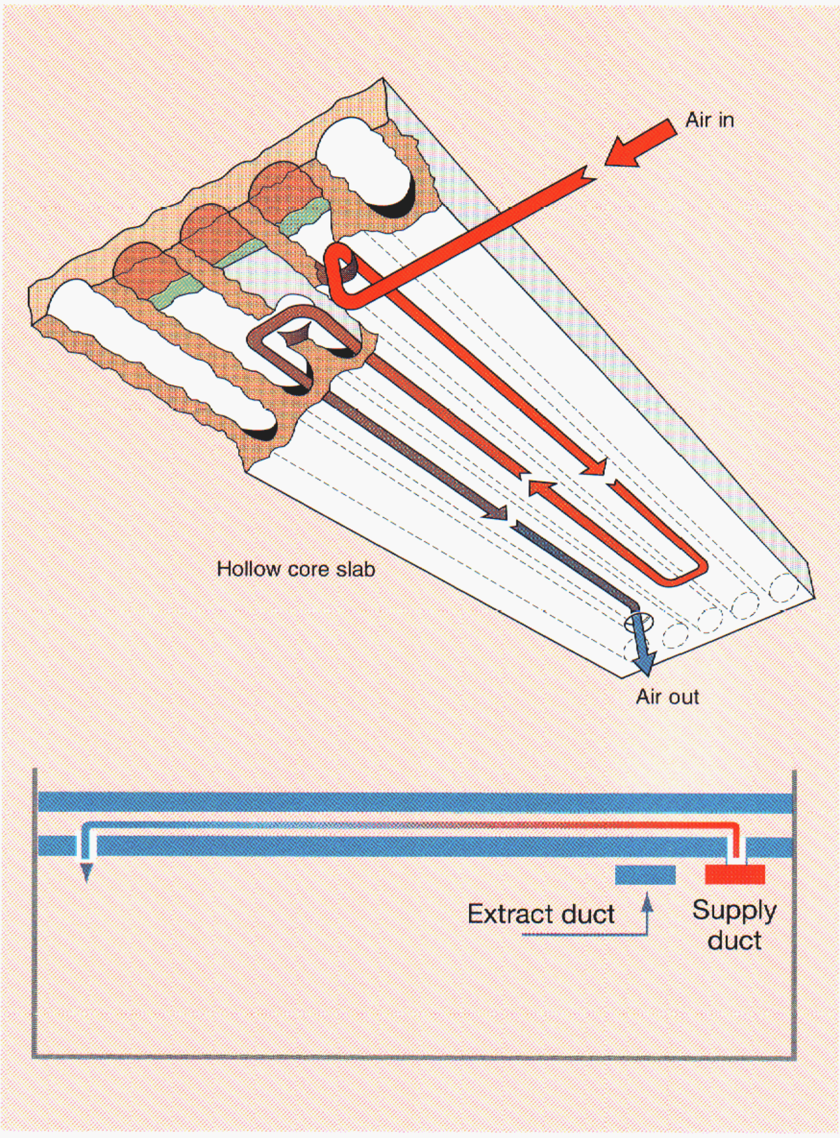
TECHNOLOGIES FOR NEW WAYS OF COOLING

HOLLOW CORE SLAB COOLING USING AIR

This system uses pre-cast concrete floor slabs with hollow cores, which can be interconnected to form air paths. The supply air is passed through dedicated air paths to bring it into thermal contact with the slab before entering the occupied space. This achieves a high rate of air/slab heat transfer (and therefore charging/discharging of cooling).

Cool night air is passed through the slabs to lower their temperature. This stored cooling is then released the following day by using the slabs to pre-cool the supply air. The lower surface of the slab is also often exposed to provide direct heat exchange with the occupied space.

Hollow core slab systems can offset heat gains of up to 30 W/m^2 where the underside of the slab is not exposed, and up to 50 W/m^2 where it is exposed.



Favourable design factors

- Large diurnal ambient temperature range with night-time temperatures below 20°C.
- Cyclical heat gains.
- Use for heat storage in winter.

Application limitations

- Better if heat gains <50 W/m^2.
- Unable to give close temperature and/or humidity control.

Design aims

- Minimise fan pressure drops.
- Avoid overcooling.
- Minimise internal and solar gains.
- Balance cooling benefit against possible impact on winter heating.

Design requirements/concerns

- Effective air/fabric thermal linking.
- Space for ventilation system.
- Provide access for cleaning of slab.

TECHNOLOGIES FOR NEW WAYS OF COOLING

ENHANCED SURFACE HEAT TRANSFER SYSTEM

This system can be installed in either floor or ceiling voids. Metal sheeting is mounted onto the surface of the slab with a small air gap into which air is supplied mechanically. The small air gap between the metal sheeting and the slab creates turbulent airflow, which significantly improves the heat transfer between the air and the slab.

This allows the slab to be pre-cooled at night for use in maintaining comfort conditions during the occupied period.

The system can operate with fans mounted in the void, or with ducted central air supply. The external air can be supplied directly into the void, or it can be supplied to the room and then re-circulated through the void.

The system provides a means of achieving thermal access to slabs in false ceilings/floors, while avoiding the need to expose the slab. It also avoids the potential problem of heating impact in winter.

Favourable design factors

- Large diurnal ambient temperature range with night-time temperatures below 20°C.
- Cyclical heat gains.
- Retrofit application.

Application limitations

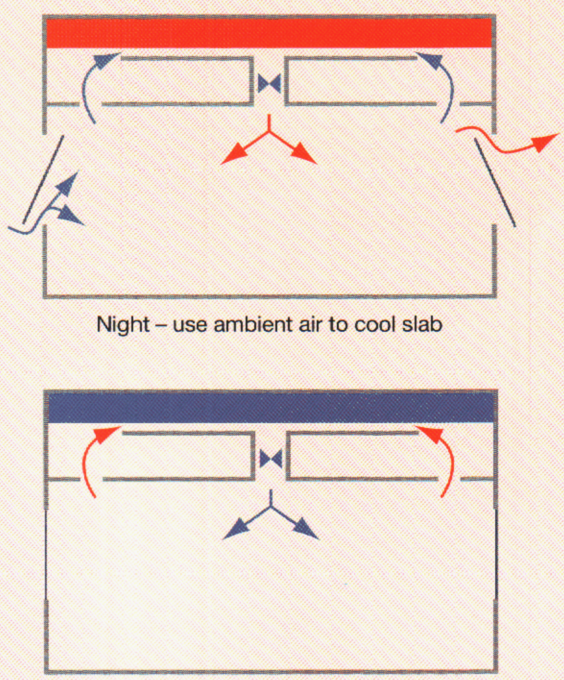
- Better if heat gains are less than 50 W/m².
- Difficult to get close temperature and/or humidity control.
- Appreciate that this is an emergent technology.
- Concern about multiple fan maintenance.

Design aims

- Minimise fan pressure drops.
- Minimise fan noise.
- Avoid overcooling.
- Minimise internal and solar gains.

Design requirements/concerns

- Space for integration into void (>200 mm).
- Provide access for cleaning.



Night – use ambient air to cool slab

Day – cooled slab reduces air temperature

TECHNOLOGIES FOR NEW WAYS OF COOLING

GROUND COUPLING USING AIR

This method utilises the natural storage energy of the earth (low sub-soil temperatures) to cool air passed through underground pipes, usually at depths of between 2 m and 5 m. The soil temperature at such depths is approximately equal to the average yearly ambient temperature. In the UK this is typically in the region of 10-14°C, providing useful cooling in the summer months.

The performance of such systems is sensitive to a number of factors, the most important being the actual soil temperature. The other major parameters that need to be considered by the designer are the air velocities and volumes, underground pipe lengths, diameters, soil conductivity, and moisture level. This sensitivity means that control of the outlet air condition from the system is limited, with the amount of sensible cooling provided being dependent on the ambient air condition.

The cooled air from the underground pipes can be used directly to provide cooling. Alternatively, for buildings that demand strict internal conditions, ground coupled air cooling can be used as pre-conditioning for any conventional ventilation or air-conditioning system.

During the heating season ground temperatures may be higher than ambient. Under these circumstances, ground coupled air systems can provide pre-heating of ventilation air.

Favourable design factors

- Ground temperature 12°C or lower.
- Located in sand/gravel and below water table.
- Movement of ground water.

Application limitations

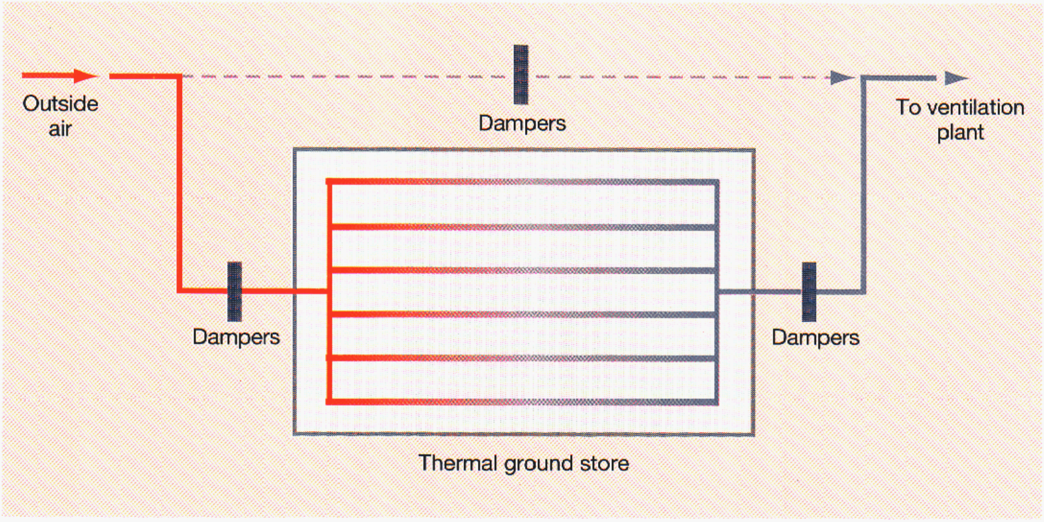
- Difficult in rocky ground.
- Scope for ground pollution, eg radon in some locations.
- Unable to give close temperature and/or humidity control.
- Possibility of microbiological growth.

Design aims

- Insulate the system from building heat gains.
- Minimise piping system pressure drops.

Design requirements/concerns

- Space for piping system.
- Access for maintenance of underground pipes.
- Sealing in wet ground.



TECHNOLOGIES FOR NEW WAYS OF COOLING

GROUND WATER COOLING (AQUIFERS)

Ground water cooling essentially consists of two well sets drilled into the ground, where water is pumped from one well set to the other via a heat exchanger, to provide useful cooling.

In areas where there is no ground water movement, the cycle can be reversed during winter. The heat collected over summer can be used for heating, this making such systems ideal for inter-seasonal storage of heating and cooling energy.

Groundwater has the benefit of greater thermal capacity per unit volume when compared with air. This allows a larger amount of energy to be stored.

In applications where there is ground water movement, the system can be used as a heat sink/source for a heat pump. Alternatively, ground water can be used as a heat sink with conventional mechanical cooling. The lower condenser temperatures lead to higher coefficients of performance (CoPs), and hence improved energy efficiency.

In the UK, the Environment Agency (see page 26 for contact details) controls the extraction and use of ground water. Contact should be made at an early stage of any project where using this technology is considered.

Favourable design factors

- Suitable aquifer geology.
- Climates with a heating and cooling season for inter-seasonal storage.

Application limitations

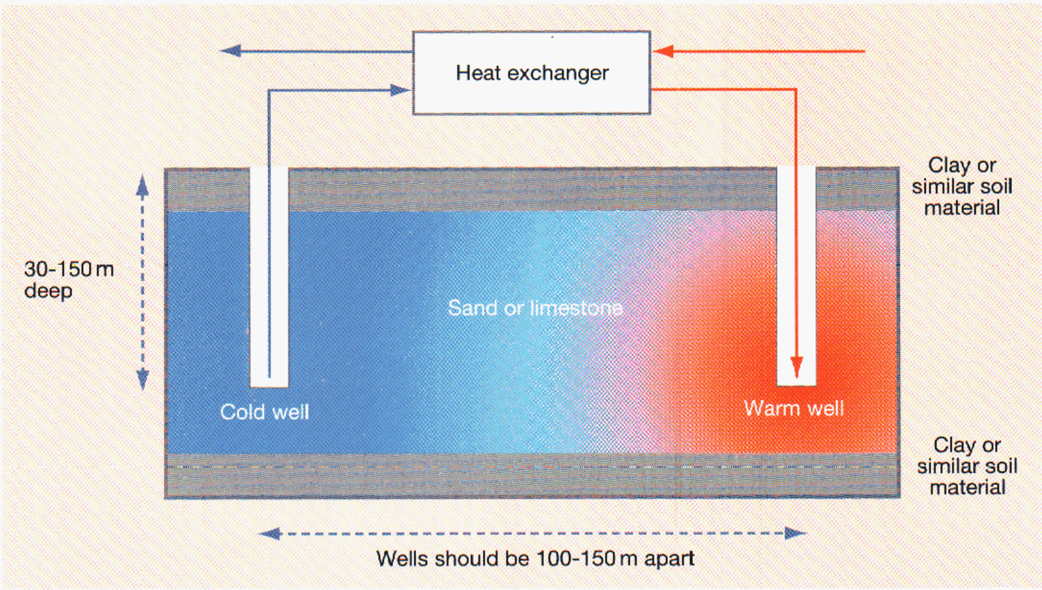
- Sometimes restrictions on use and cost of extraction of ground water.
- Ground water movement would compromise inter-seasonal storage.
- Limited storage flexibility.
- Appreciate that the technology is relatively new to the UK.

Design aims

- Balancing the cooling and heating extracted.

Design requirements/concerns

- Cold and warm well sets should be 100-150 m apart.
- Space for heat exchanger.
- Maintenance of well pump sets.

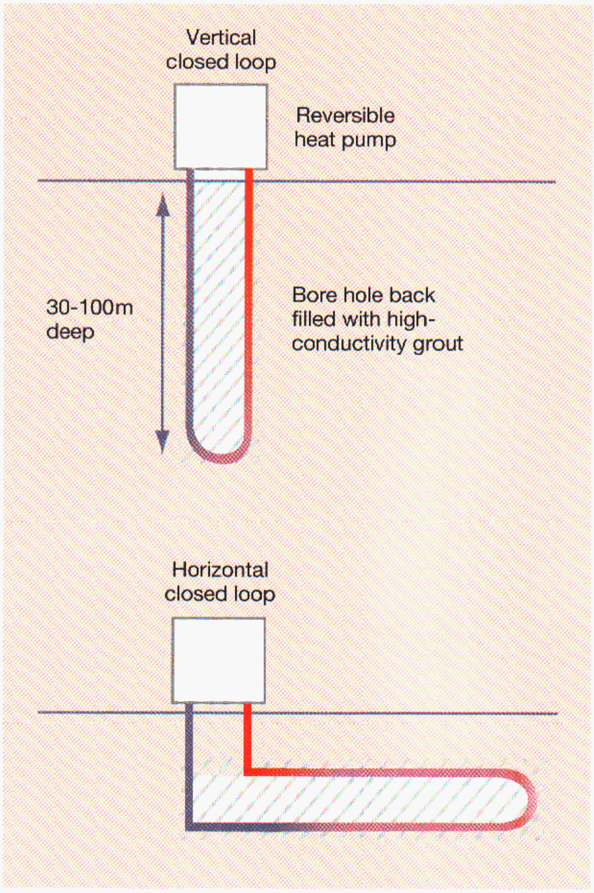


TECHNOLOGIES FOR NEW WAYS OF COOLING

GROUND COUPLED HEAT PUMPS

This system uses the thermal mass of the ground as a heat sink or heat source to improve the CoP of a reversible heat pump. The temperature of the ground in the UK at 2-5 m is typically in the region of 10-14ºC. At a depth of around 2 m the annual temperature swing is only 8ºC, while at a depth of 50 m the ground temperature is stable.

Ground coupled heat pump systems consist of a continuous loop of high-density polyethylene pipe, filled with a water/antifreeze mix, buried in the ground. The closed loops can run vertically or horizontally.



Vertical loops are inserted as U-tubes into small bore holes (about 130 mm in diameter), and up to 100 m deep. These are then back-filled with high-conductivity grout to seal the bore and prevent cross-contamination of aquifers. Vertical loops have a higher installation cost, but provide better performance than horizontal loops.

Horizontal loops use U-tubes buried horizontally in trenches typically 2 m deep, which are back filled with fine aggregate. Horizontal loops have a lower excavation cost, but take up a greater ground area. The performance of horizontal loops is affected by the proximity to the surface (solar heat gain and rainfall evaporation).

In both cases, the performance can be enhanced where there is movement of ground water across the loop.

Favourable design factors

- Suitable geology, eg high soil conductivity.
- Climates with definite heating and cooling season.
- Movement of ground water.

Application limitations

- Legislative or regulatory restrictions.
- Unsuitable site hydrology, characteristics, and space restrictions.

Design aims

- Reduced electrical consumption from better CoP.
- Accurately matching building demand to the capacity of the system.

Design requirements/concerns

- High excavation costs prohibit the provision of spare capacity.

TECHNOLOGIES FOR NEW WAYS OF COOLING

SURFACE WATER COOLING (SEA/RIVER/LAKE)

Use of the sea, rivers, and lakes for cooling buildings is achieved by pumping water from these sources (preferably at depth) by an open loop system and extracting cooling via a heat exchanger. The surface water can be used to directly cool the space/supply air or to pre-cool the chilled water circuit. The effectiveness of direct cooling will depend on the temperature and variability of the surface water.

The system can be used to cool the building directly. Alternatively, the surface water can be used as a heat sink/source for a heat pump or as a heat sink with conventional mechanical cooling. The lower condenser temperatures lead to higher CoPs and hence improved energy efficiency. In the UK, the Environment Agency (see page 26 for contact details) controls the extraction and use of surface water. Contact should be made at an early stage of any project where using this technology is considered.

Favourable design factors

- Proximity to suitable surface water source.

Application limitations

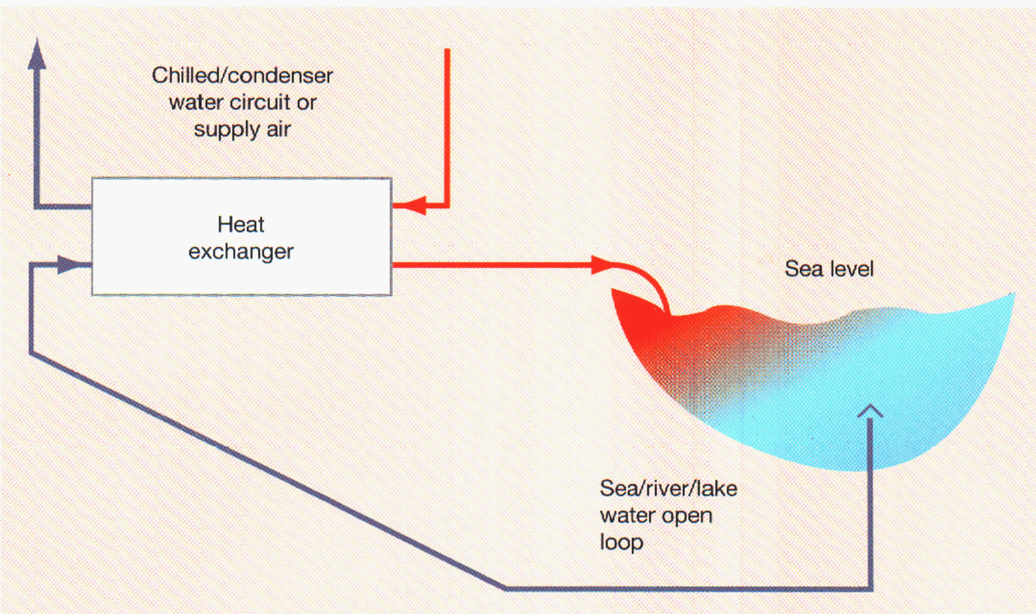
- Great depth required to reach cold water.
- Salinity of sea water encouraging corrosion in equipment.
- Legislation/regulation restricting surface water use.
- Possible ecological effects of raising surface water temperatures.

Design aims

- Minimise cold water source pumping costs.
- Minimise corrosion and fouling possibilities.
- Compatibility with conventional cooling systems.

Design requirements/concerns

- Space for heat exchanger, etc.



TECHNOLOGIES FOR NEW WAYS OF COOLING

EVAPORATIVE COOLING (DIRECT/INDIRECT)

Water evaporated in non-saturated air will produce a drop in the dry bulb temperature and an associated rise in the moisture content of the air. This process is termed 'adiabatic', where the sensible heat removed from the air equals the latent heat absorbed by the water evaporated as heat of vapourisation.

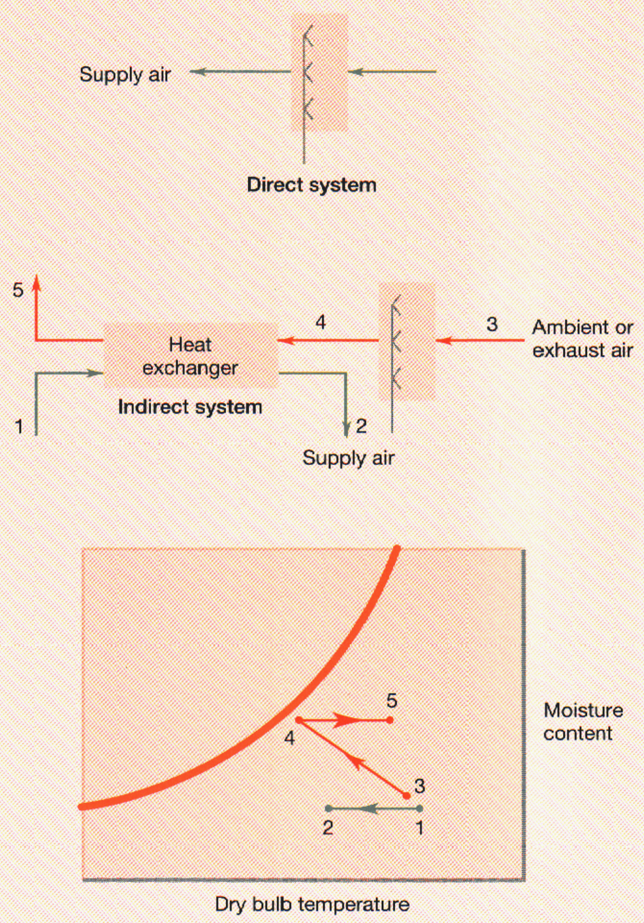
Evaporative cooling can be applied using the following methods:

- direct evaporative cooling
- indirect evaporative cooling
- direct and indirect evaporative cooling in combination.

Direct evaporative cooling is where the evaporation process takes place in the supply air stream. Indirect evaporative cooling is where the exhaust air stream is cooled using evaporation and then used to cool the supply air via a heat exchanger. A combined system combines these two technologies in series to increase the cooling delivered.

With conventional cooling systems, when conditions are favourable, evaporative cooling can be used to directly cool the chilled water in a cooling tower, bypassing the chiller (the 'Strainer Cycle').

Alternatively, evaporative cooling can provide pre-cooling of ambient air onto dry air coolers. The lower water temperatures in this system reduce the risk of legionella compared to a conventional wet cooling tower.



Favourable design factors

- Low ambient air humidity.

Application limitations

- Difficult to provide close temperature and/or humidity control.
- Legionella concern, although risk limited by low water temperatures.
- Larger plant than conventional system with similar cooling loads.
- Need to consider water consumption/cost.

Design aims

- Integration with conventional systems.
- Heat exchanger in indirect systems can be used for heat recovery in winter if in exhaust air.

Design requirements/concerns

- Space required for ventilation system and heat exchanger.

TECHNOLOGIES FOR NEW WAYS OF COOLING

DESICCANT DEHUMIDIFICATION AND EVAPORATIVE COOLING

Desiccants are hygroscopic materials that are able to absorb water vapour from the surrounding atmosphere. Desiccants can be liquid or solid, both of which are used in HVAC applications.

Liquid desiccants work by absorption, where moisture is absorbed in a chemical reaction. Solid desiccant materials with large internal surface areas work by adsorption, where moisture is drawn into the material by capillary action. In both, regeneration is achieved by heating the desiccant to drive off the moisture.

Desiccant dehumidification offers an alternative to using mechanical refrigeration to dehumidify. Desiccant dehumidification does require a heat source, typically from natural gas or waste heat from other processes, to regenerate the desiccant material. Modern desiccant materials require regeneration temperatures of between 60°C and 90°C, which are compatible with conventional hot water heating systems.

Desiccant dehumidification can also be used in conjunction with evaporative cooling, as shown in the technical diagram below. The desiccant wheel removes moisture from incoming air, taking it to condition (2), while the thermal wheel (or another heat exchanger) cools it to condition (3). There is then the option of further evaporative or mechanical cooling before the air is supplied to the space (4). Extract air at the room condition (5) is evaporatively cooled to condition (6), which enables the thermal wheel to cool the supply air. The extract air (7) is then heated further, to enable it to drive moisture off the desiccant wheel, leaving the system at condition (9).

Favourable design factors

- Waste heat or cheap thermal source available.
- High electricity costs.
- Requirement for low humidity or dew point temperature (for dessicant dehumidification alone).

Design aims

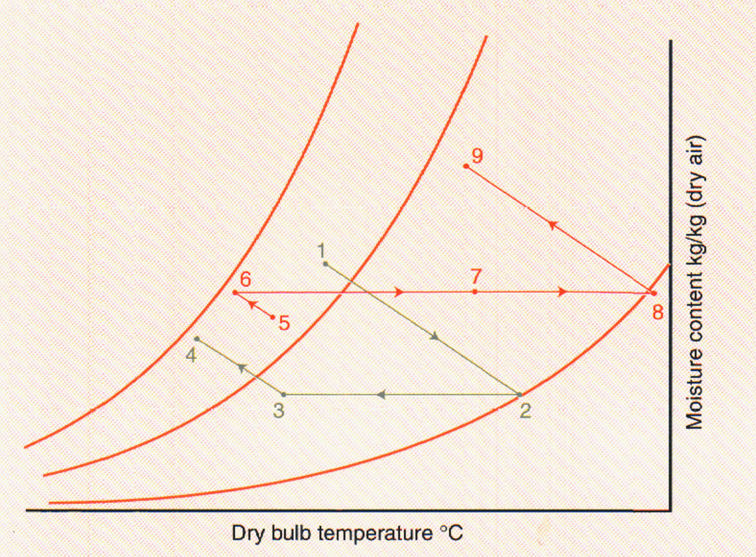
- Air filters to increase life span of desiccant material.
- Use of desiccant wheel for heat and moisture recovery in winter.
- Good control systems to avoid unnecessary regeneration.

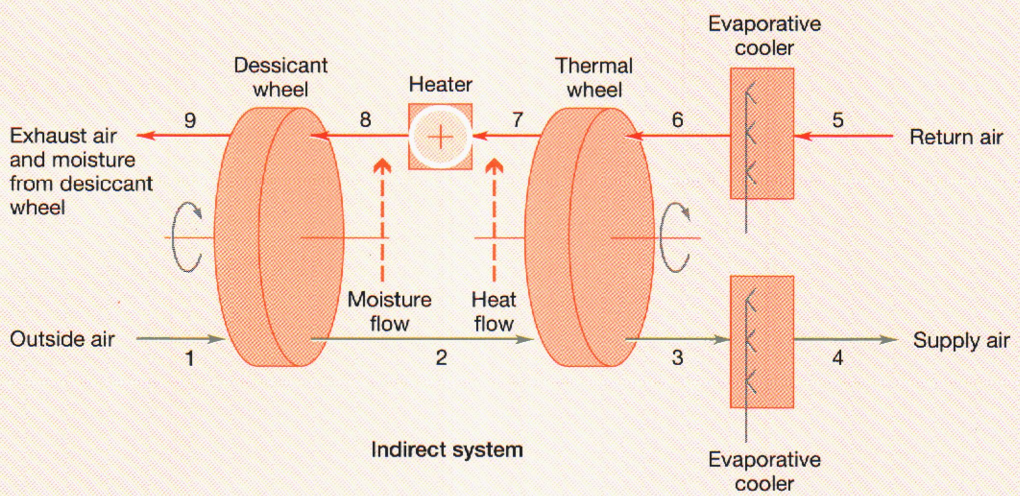
Application limitations

- Difficult to provide close temperature and/or humidity control.
- Reduced performance in dry climates.
- Need to consider water consumption/cost.

Design requirements/concerns

- Usually a full fresh air system; air recirculation not normally feasible.
- Space for ventilation system.
- Supply and extract air streams normally adjacent.
- Mechanical cooling often still required.





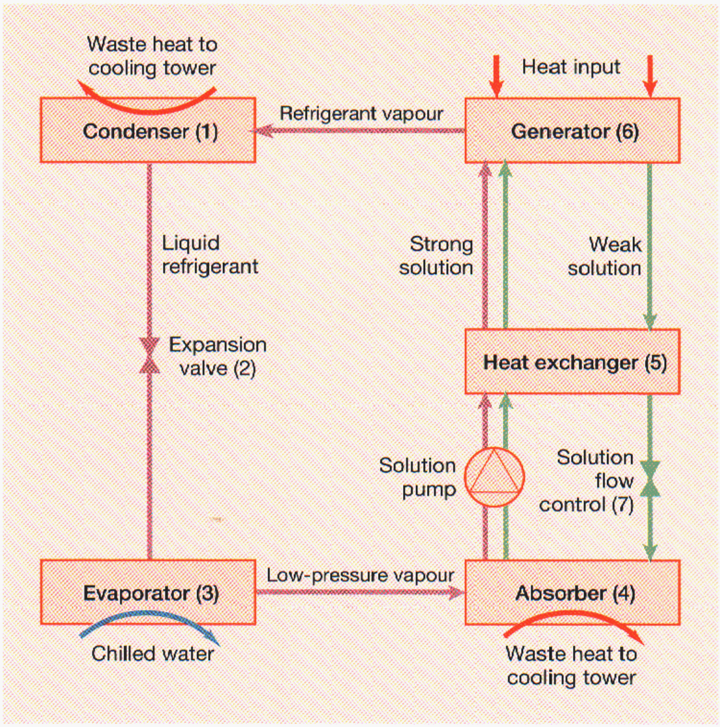
Indirect system

TECHNOLOGIES FOR NEW WAYS OF COOLING

ABSORPTION COOLING

Absorption refrigeration cycles are similar to vapour compression cycles in that the cooling effect derives from the expansion of a refrigerant from a relatively high to a relatively low pressure. The low pressure is created by the affinity of a liquid (the absorbent solution) to draw the refrigerant gas into solution. Instead of using an electrically driven mechanical compressor, the high pressure in the refrigerant is generated when direct heat is used to vaporise the refrigerant from the solution. The refrigerants used in absorption cycles are typically ammonia with water as the absorbent solution or water as the refrigerant with lithium bromide as the absorbent solution.

The basic components of an absorption system are an evaporator (3) and an absorber (4) on the low-pressure side of the system, and a generator (6) and condenser (1) on the high-pressure side of the system. High-pressure liquid refrigerant from the condenser (1) passes into the evaporator (3) through an expansion device (2) that allows its pressure to reduse to the relatively low pressure in the evaporator. The liquid refrigerant vapourises in the evaporator (3), absorbing heat from the material being cooled (eg chilled water). The vapour then passes into the absorber (4), where it is drawn into solution with the absorbent. This process maintains the low pressure in the evaporator (3), and gives off heat, which is rejected through a cooling tower.



As the refrigerant vapour dissolves into the absorbent solution, it increases the strength and vapour pressure of the solution. To maintain the vapour pressure of the solution low enough to keep absorbing the refrigerant and thus provide the required low pressure and temperature in the evaporator, the strong solution is pumped to the (re)generator (6) where the refrigerant is separated from the absorbent by heating the solution and vapourising the refrigerant. The high-pressure refrigerant is passed to the condenser (1), where it is condensed to a high-pressure liquid, using water from a cooling tower to reduce its temperature. the weak absorbent solution is returned to the absorber (4) via a heat exchanger (5) which serves to pre-heat the strong solution on its way to the generator, and a flow control device (7) to maintain the pressure differential.

The heat supplied to drive the refrigerant vapour out of the absorbent solution in the generator (6) is usually low-pressure steam or hot water.

Favourable design factors

- Waste heat or cheap thermal source available.
- Spare boiler capacity.
- High electricity costs.

Application limitations

- Low CoP.

Design aims

- Optimise cooling water temperature difference.

Design requirements/concerns

- Heat input for regeneration >90°C
- Large capacity heat rejection.

TECHNOLOGIES FOR NEW WAYS OF COOLING

ICE STORAGE

Ice storage normally involves the use of an ice storage tank in combination with conventional HVAC equipment to shift the period of chiller operation from peak to off-peak periods. The ice storage cycles are usually daily, although weekly and seasonal cycles are also used. Ice storage systems use the latent heat of fusion of ice to store cooling energy at 0°C. In ice storage systems the refrigeration plant generates an ice bank during off-peak periods, which is melted to provide chilled water for use during peak periods. Ice storage systems offer the primary benefit of load smoothing for the electricity generator, and savings in running costs for the user due to off-peak electricity tariffs, rather than lower energy consumption.

The storage capacity of the system can be sized to shift all or just part of the cooling demand from peak to off-peak periods. The criteria for determining the storage capacity are generally economic factors such as off-peak electricity tariffs, cost savings from reduced chiller capacity, and provision of plant space.

Full storage systems supply the cooling requirements for the entire operating period from storage. This allows all the cooling demand to be shifted to off-peak periods. Partial storage systems supply only part of the total cooling energy, and the system is sized such that the combined output of storage and chiller meet the peak design cooling demand. Partial storage systems offer the benefit of minimising the size of storage and refrigeration equipment, but as only a proportion of the cooling demand is shifted to off-peak periods the cost savings will be less.

Favourable design factors

- Large differential between peak and off-peak electricity costs.

Application limitations

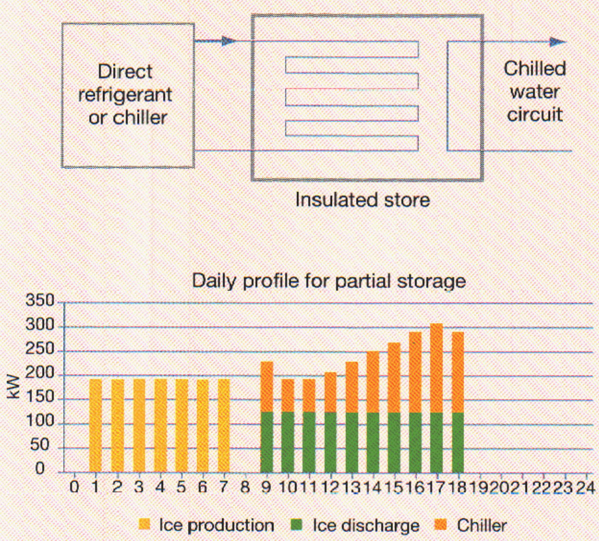
- Needs increased plant space.
- Requires more complicated control strategy than conventional systems.
- Can have reduced response flexibility.
- Energy consumption is increased, although cost may be less.

Design aims

- Shift load demand from peak tariff to off-peak tariff.
- Reduced maximum electrical demand.
- Reduced chiller size for partial storage systems.

Design requirements/concerns

- Accurate data for building cooling load profile (daily/weekly/seasonal).
- Effective control strategy that is specific to application and system configuration.



TECHNOLOGIES FOR NEW WAYS OF COOLING

SLAB COOLING USING WATER

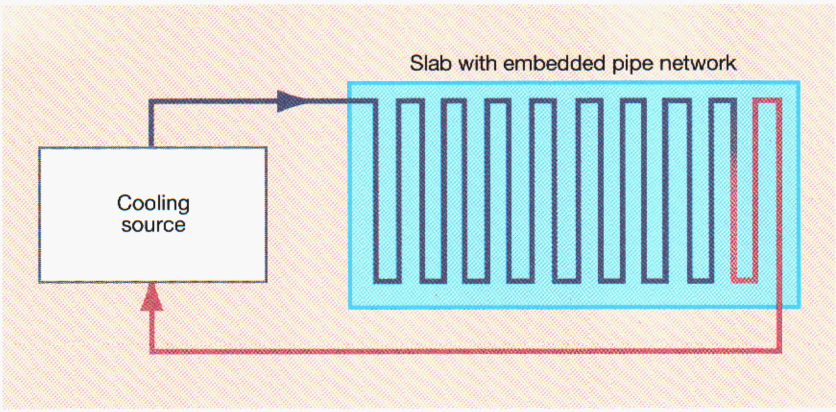
A pipe network is embedded in the structural slab or in a floating slab about 70 mm thick and located on the bearing slab. Typically the ceiling slab is used, although the floor slab can also function to a lesser extent. The system provides cooling via convective and radiant heat transfer.

Cooling energy is stored in the slab whenever the temperature of the circulating water is lower than the temperature of the slab. The slab then provides cooling to the space when the slab temperature is less than the air temperature.

The water in the circuit can be cooled from a variety of sources:

- cooling tower
- ground water
- vapour compression chiller
- absorption chiller
- dry cooler.

The large area means that the smaller temperature differentials between air and water, which are given by some low-energy cooling sources, can be utilised.



Favourable design factors

- Compatible with low-energy/quality sources of cooling.

Application limitations

- Best if heat gains <50 W/m².
- Difficult to provide close temperature and/or humidity control.
- Less able to handle high internal and solar gains.

Design aims

- Avoid condensation problems by controlling supply air humidity.
- Surface to air temperature differential <4°C.
- Use system for heating in winter.

Design requirements/concerns

- Pipework connections accessible.
- Effective slab/air thermal linking.
- Adequate space for central cooling and distribution system.

The water is typically supplied at between 15°C and 18°C. When supplied by a cooling tower or dry cooler the system can operate as a form of night cooling system, storing cooling energy at night to offset heat gains the following day.

Because the slab is relatively cool, it provides mainly radiant cooling to the occupants. This may allow the air temperature to be slightly higher while still giving satisfactory comfort conditions.

Cooled floors can provide 30-40 W/m² of cooling with water supplied at 22°C and the occupied space at 26°C. Cooled ceilings can provide 40-50 W/m² of cooling with water supplied at 20°C and the occupied space at 26°C.

TECHNOLOGIES FOR NEW WAYS OF COOLING

CHILLED BEAMS/CEILINGS

These cooling units are often integrated with suspended ceilings. Cooling is provided by circulating water, at the relatively high cooling temperature of about 16°C, through the units. Chilled beams rely on convective air movement to provide cooling to the room, while chilled ceilings have flat panel units, which transfer cooling to the space by radiation and convection. Energy savings are achieved by being able to use low-energy cooling technologies to provide the cooling water or from improved CoP due to higher water operating temperatures.

Chilled beams can provide about 60 W/m^2 of cooling with cooling water supplied at 16°C and the occupied space at 26°C.

Chilled ceilings can provide about 40 W/m^2 of cooling, assuming 50% active area with cooling water supplied at 16°C and the occupied space at 26°C.

The performance of both is approximately proportional to cooling water/occupied space temperature differential, and the output from chilled beams can vary considerably with design.

Favourable design factors

- Compatible with low-energy/quality sources of cooling.

Application limitations

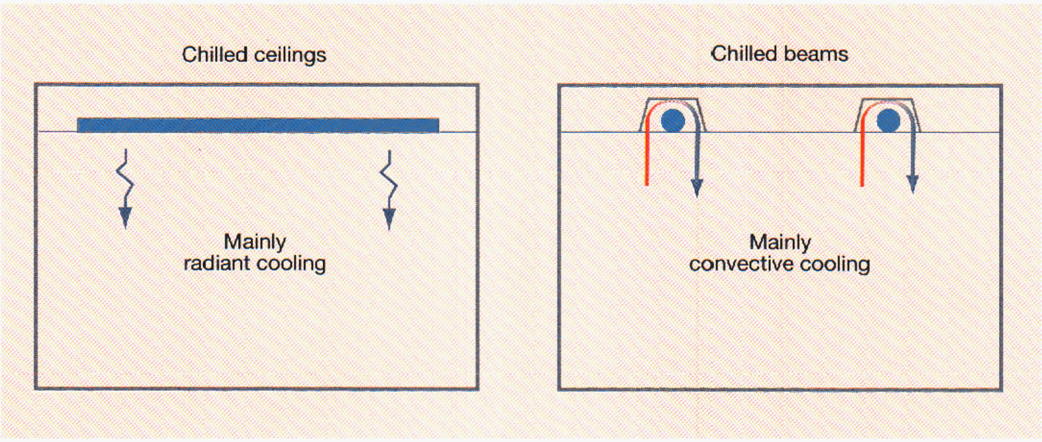
- Less able to provide close temperature and/or humidity control.

Design aims

- Avoid condensation problems on the chilled surfaces by controlling supply air humidity.

Design requirements/concerns

- Space for cooling elements.
- Adequate space for central cooling and distribution system.



TECHNOLOGIES FOR NEW WAYS OF COOLING

DISPLACEMENT VENTILATION

Displacement ventilation is buoyancy-driven air movement within the space rather than forced, as is the case for conventional mixed ventilation systems. Cool air is gently introduced into the conditioned space at low level. This spreads slowly across the space, providing a source of cool air for convective plumes, which form around local heat sources such as people and office equipment. The plumes spread out below the ceiling to form a warm stratified layer from which the air is extracted.

The temperature of the stratified layer near the ceiling can be allowed to rise above comfort conditions because it is above the occupied zone. The higher extract temperature allows for a greater temperature differential between supply and extract, giving greater cooling capacity. The higher supply temperature also improves the CoP to achieve energy savings.

The cooling capacity of displacement ventilation systems is about 40 W/m^2. The rate of air supply is typically around 4 air changes per hour.

Favourable design factors

- Surface temperature of heat sources >35°C.
- Higher supply temperature enables higher CoP.

Application limitations

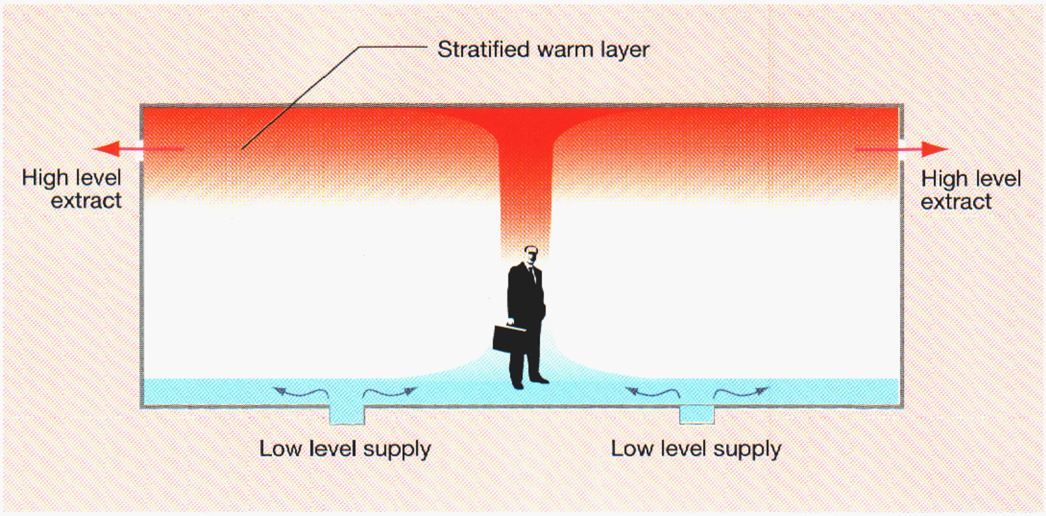
- Unable to provide close temperature and/ or humidity control.
- Susceptible to strong disturbances to air flows, eg occupancy movement or downdrafts.

Design aims

- Supply air temperature >18°C.
- Space vertical temperature gradient <1.5°C/m.

Design requirements/concerns

- Large floor-to-ceiling height required (ie >2.7 m).
- Space for low-velocity air terminal devices at low level.



TECHNOLOGIES FOR NEW WAYS OF COOLING

CONVENTIONAL HVAC SYSTEMS

Conventional HVAC systems include all electrically driven systems and components, such as:

- fan coils
- direct expansion units
- heat pumps
- variable air volume systems
- chillers
- condensers
- cooling towers
- dry air coolers.

Essentially these are systems that use the vapour compression cycle as the source of cooling. Conventional HVAC systems are generally required when close temperature/humidity control is required, or where internal gains are very high. Conventional systems can be used in combination with low-energy technologies to achieve satisfactory environmental control while delivering lower energy consumption.

Further details of these systems can be found in GPG 290 and GPG 291 (see page 26).

Favourable design factors

- Close temperature/humidity control.
- High internal gains.
- High solar gains.
- Established technology.
- Flexibility and adjustability.

Application limitations

- High capital and running costs.
- Environmental concerns.

Design aims

- Use of free cooling with fresh air control.
- Use of advanced/adaptive controls to minimise wastage.
- Integration with low-energy cooling technologies.

Design requirements/concerns

- Space allowance for chiller plant and associated equipment.

3 TECHNOLOGY COMBINATIONS

Note that the combinations shown in the matrix are the more common applications and are not exclusive.

Key:
S – series combination
P – parallel combination

	Night-time cooling with natural ventilation	Night-time cooling with mechanical ventilation	Hollow core slab cooling using air	Enhanced surface heat transfer system	Ground coupling using air	Ground water cooling (aquifers)	Ground coupled heat pumps	Surface water cooling (sea/river/lake)	Evaporative cooling (direct and indirect)	Desiccant dehumidification and evaporative cooling	Absorption cooling	Ice storage	Slab cooling using water	Chilled beams/ceilings	Displacement ventilation	Conventional HVAC systems
Night-time cooling with natural ventilation																
Night-time cooling with mechanical ventilation			S	S	S				S	S					P	
Hollow core slab cooling using air		S													P	
Enhanced surface heat transfer system		S													P	
Ground coupling using air		S											P	P	S	
Ground water cooling (aquifers)													S	S	S	S
Ground coupled heat pumps																
Surface water cooling (sea/river/lake)													S	S	S	S
Evaporative cooling (direct and indirect)		S													S	S
Desiccant dehumidification and evaporative cooling		S													S	
Absorption cooling													S	S	S	S
Ice storage																S
Slab cooling using water					P	S		S							P	S
Chilled beams/ceilings					P	S		S			S				P[1]	S
Displacement ventilation		P	P	P	S	S		S	S	S	S		P	P[1]		S
Conventional HVAC systems						S		S	S		S	S	S	S	S	

Note:
1 Only chilled ceilings are suitable for use in combination with displacement ventilation.

TECHNOLOGY COMBINATIONS

WORKED EXAMPLE

The example below indicates how the matrix can be used to identify possible combinations. Beginning with displacement ventilation, and travelling horizontally along the matrix, a number of combinations are possible, and two of these are highlighted. The first is ground cooling water (aquifers), which can be used in series with displacement ventilation. The second is chilled ceilings, which can be used in parallel with displacement ventilation.

A series combination indicates that one technology is used to provide a sink for heat rejection from another technology, while a parallel combination indicates that two technologies can operate independently, yet in a compatible way, to provide cooling.

Key:
S – series combination
P – parallel combination

	Night-time cooling with natural ventilation	Night-time cooling with mechanical ventilation	Hollow core slab cooling using air	Enhanced surface heat transfer system	Ground coupling using air	Ground water cooling (aquifers)	Ground coupled heat pumps	Surface water cooling (sea/river/lake)	Evaporative cooling (direct and indirect)	Desiccant dehumidification and evaporative cooling	Absorption cooling	Ice storage	Slab cooling using water	Chilled beams/ceilings	Displacement ventilation	Conventional HVAC systems
Night-time cooling with natural ventilation																
Night-time cooling with mechanical ventilation			S	S	S				S	S					P	
Hollow core slab cooling using air		S													P	
Enhanced surface heat transfer system		S													P	
Ground coupling using air		S											P	P	S	
Ground water cooling (aquifers)													S	S	S	S
Ground coupled heat pumps																
Surface water cooling (sea/river/lake)													S	S	S	S
Evaporative cooling (direct and indirect)		S													S	S
Desiccant dehumidification and evaporative cooling		S													S	
Absorption cooling													S	S	S	S
Ice storage																S
Slab cooling using water					P	S		S							P	S
Chilled beams/ceilings					P	S		S			S				P[1]	S
Displacement ventilation		P	P	P	S	**S**		S	S	S	S		P	**P[1]**		S
Conventional HVAC systems						S		S	S		S	S	S	S	S	

Note:
1 Only chilled ceilings are suitable for use in combination with displacement ventilation.

4 CONCLUSIONS AND FURTHER READING

CONCLUSIONS

The information provided in this Report is intended to make more users aware of the alternatives available for cooling. The take-up of these technologies will be affected by several factors. These include capital/running costs, thermal comfort delivered, availability of design expertise, etc. Such information is provided as part of the 'SELECT' software tool available from BRECSU Enquiries Bureau (see the back cover for contact details).

The increased use of information technology is leading to higher building heat gains, and hence a greater demand for cooling. Even where a low-energy cooling technology is unable to deliver the level of thermal comfort required, it may still provide energy savings as part of a system that includes conventional technologies.

CONTACT

Environment Agency

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Surrey GU16 7SQ. Tel 0845 933 3111
E-mail enquiries@environment-agency.gov.uk
Website www.environment-agency.gov.uk

FURTHER READING

BRE

Bucknalls Lane, Garston, Watford WD25 9XX
Tel 01923 664262. E-mail bookshop@bre.co.uk
Website www.bookshop.com

- IEA Annex 28 'Design tools for low energy cooling. Technology selection and early design guidance'
- BRE Digest 'Thermal mass in office buildings'

Chartered Institution of Building Services Engineers (CIBSE)

222 Balham High Road, Balham, London
SW12 9BS
Tel 020 8675 5211. Fax 020 8675 5449
Website www.cibse.org

- Applications Manual (AM)10 'Natural ventilation in non-domestic buildings'

Building Services Research and Information Association (BSRIA)

Old Bracknell Lane West, Bracknell, Berkshire
RG12 7AH
Tel 01344 426511. Fax 01344 487575
Website www.bsria.co.uk

- Final Report 5/96 'Night cooling control strategies'
- Technical Note (TN) 16/95 'Pre-cooling in mechanically cooled buildings'

ASHRAE

1791 Tullie Circle, NE, Atlanta, GA 30329
Tel 404 636 8400. Fax 404 321 5478
Website www.ashrae.org

- 'HVAC Systems and Equipment Handbook', chapter 6, 'Panel Heating and Cooling'

FURTHER READING

ENERGY EFFICIENCY BEST PRACTICE PROGRAMME DOCUMENTS

The following Best Practice programme publications are available from the BRECSU Enquiries Bureau. Contact details are given overleaf.

Energy Consumption Guide

19 Energy use in offices

General Information Report

31 Avoiding or minimising the use of air-conditioning. A research report from the EnREI Programme

Good Practice Case Study

334 The benefits of including energy efficiency early in the design stage – Anglia Polytechnic University

Good Practice Guides

237 Natural ventilation in non-domestic buildings – a guide for designers, developers and owners

257 Energy-efficient mechanical ventilation systems

287 The design team's guide to environmentally smart buildings – energy-efficient options for new and refurbished offices

290 Ventilation and cooling option appraisal – a client's guide

291 A designer's guide to the options for ventilation and cooling

New Practice Case Studies

102 The Queen's Building, De Montfort University – feedback for designers and clients

106 The Elizabeth Fry Building, University of East Anglia – feedback for designers and clients

114 The Inland Revenue Headquarters – feedback for designers and clients

115 The Ionica Building, Cambridge – feedback for designers and clients

118 Comfort without air-conditioning in refurbished office – an assessment of possibilities

124 The Edinburgh Gate Building, Harlow – feedback for designers and clients

NatVent® Guide

Natural ventilation in office buildings

The Government's Energy Efficiency Best Practice programme provides impartial, authoritative information on energy efficiency techniques and technologies in industry and buildings. This information is disseminated through publications, videos and software, together with seminars, workshops and other events. Publications within the Best Practice programme are shown opposite.

Visit the website at **www.energy-efficiency.gov.uk**
Call the Environment and Energy Helpline on **0800 585794**

For further specific information on:

Buildings-related projects contact:
Enquiries Bureau

BRECSU
BRE
Garston, Watford WD25 9XX
Tel 01923 664258
Fax 01923 664787
E-mail brecsuenq@bre.co.uk

Industrial projects contact:
Energy Efficiency Enquiries Bureau

ETSU
Harwell, Oxfordshire
OX11 0RA
Tel 01235 436747
Fax 01235 433066
E-mail etsuenq@aeat.co.uk

Energy Consumption Guides: compare energy use in specific processes, operations, plant and building types.

Good Practice: promotes proven energy-efficient techniques through Guides and Case Studies.

New Practice: monitors first commercial applications of new energy efficiency measures.

Future Practice: reports on joint R&D ventures into new energy efficiency measures.

General Information: describes concepts and approaches yet to be fully established as good practice.

Fuel Efficiency Booklets: give detailed information on specific technologies and techniques.

Introduction to Energy Efficiency: helps new energy managers understand the use and costs of heating, lighting, etc.